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ERTS DATA USER INVESTIGATION TO DEVELOP A
MULTI-STAGE FOREST SAMPLING INVENTORY SYSTEM

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16. Abstract A system to provide precision annotation of predetermined forest inventory sampling units on the ERTS-1 MSS images was developed. In addition, an annotation system for high altitude U2 photographs was completed. MSS bulk image accuracy is good enough to allow the use of one square mile sampling units. IMANCO image analyzer interpretation work for small scale images demonstrated the need for much additional analyses. Continuing image interpretation work for the next reporting period is concentrated on manual image interpretation work as well as digital interpretation system development using the computer compatible tapes.			
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PREFACE

During the past reporting period we have developed a system to provide precision annotation of predetermined forest inventory sampling units on the ERTS-1 MSS images. The significant results of the geometric accuracy investigation of the MSS images is that good accuracy can be obtained with the use of the collinearity equations. A resection for 1/16 of one image with 18 known points provided a maximum RMSE of 144 meters on the ground. Another resection for 1/6 of an image with 30 known points provided a maximum RMSE of 215 meters on the ground. With these accuracy results it seems possible to use the one-square-mile land section as a primary sample unit on the ERTS MSS images without suffering a decrease in sampling efficiency due to spatial misregistration.

IMANCO Quantimet image analyzer interpretation work for small scale images performed during the past reporting period has shown the need for much additional work to assess its interpretation potential.

Interpretation work continues with manual interpretation of the U2 and ERTS MSS images as well as with the development of a digital interpretation capability using the computer-compatible tapes.

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1.0 INTRODUCTION

This report describes the progress made in the ERTS-1 investigation concerning the development of a multistage forest inventory system. Such an inventory system utilizes aerial and space platform imagery as well as ground data in a sampling framework through which timber volume estimates are obtained. The main objective of the present investigation is to evaluate the usefulness of ERTS-1 imagery for the space platform stage of the inventory.

A minor objective is to refine and develop new techniques to make optimum use of the information available, not only at the space level, but also at the subsequent aircraft levels.

To make this report as self-contained as possible we will briefly outline the background and objectives of the investigation as they relate to the six-month reporting period.

This extended introduction will then be followed by a description of the work accomplished and the technical results obtained to date. We will conclude the report with a projection of the investigative work for the coming reporting interval. Conclusions for the present six-month reporting period will be presented in the last part of the report.

2.0 BACKGROUND

Multistage variable probability sampling is a method in which the probabilities for the selection of the sample units at stage $n+1$ are based on criteria evaluated from the sample units at stage n . With n increasing, the total ground area sampled decreases until in the final stage a number of ground units is visited. At the same time the expense incurred in the evaluation of a unit on the ground increases with n . For a forest inventory, the extremes are the complete evaluation of a unit on the ground on one hand, and the separation of land into forest and non-forest classes on space imagery on the other. The direct combination of these extremes is not always possible. Therefore, to tie the extremes together, intermediate stages, consisting of aerial imagery, are used to provide a correlation chain through which the first and the last stage are connected. If this chain had a bad link, the survey would be clearly inefficient and ineffective. On the other hand, however, a great deal could be gained by improving the links between stages.

In general, improvements of this type can be made in respect to the following three aspects of a multistage timber inventory:

- a. Development of aspects of sampling-theory to account for the types of relationships present between variables extracted from the imagery at adjacent levels. It is a well-known fact, for instance, that in straight-forward variable probability sampling the relationship between these variables should be a straight line through the origin, in order to obtain maximum efficiency.

b. Spatial correspondence between sample units on adjacent stages of aerial or space imagery. To our knowledge no research has yet been performed to establish the sensitivity of the sampling variance in relation to spatial mismatches between sample units at different stages. However, by using a precision image annotation process, mismatches can be avoided so that this type of error can be omitted from consideration, thereby leaving fewer and more important issues for investigation at the present stage of our research.

c. Extraction of desired information from the imagery. The greatest overall gain can be obtained in this area in terms of both accuracy and efficiency. One problem with the use of high altitude space and aerial imagery for forest inventories has been that the traditional photo interpretation techniques based on crown closure and crown cover are not applicable at these altitudes. However, information on the distribution of forest and other vegetative types is definitely present, but has to be extracted with novel techniques in the framework of the multistage inventory. With the advent of ERTS, superior multispectral space imagery has become available for the multistage inventory and the evaluation of the usefulness of this imagery is the major objective of the present investigation.

Corresponding to the above three main areas of improvement of multistage forest inventories, our contract was divided into three main tasks, each with an ERTS component as well as containing proposed methods to be investigated for improved use of aerial imagery.

The work accomplished during the past six-month period was primarily focussed on Task II: sample unit annotation on aerial and space imagery, and Task III: interpretation methods. The work accomplished in the context of Task I: sampling theoretical formulation, relates heavily to its final use with the ERTS and U2 RC10 image interpretation data and will therefore be reported on in the final report under the present contract.

Task II was logically carried out before Task III, as one needs to know the spatial location of the sample units on the imagery before any interpretation can be attempted. However, the sample units on the 1:40,000 aerial imagery had been annotated under a previously executed multistage inventory so that interpretation research for this stage could be carried out simultaneously with the work for Task II.

3.0 OBJECTIVES

A recent application of the multistage inventory concept to commercial property in the State of California demonstrated the need for the annotation of ownership patterns on aerial imagery. In this instance, clusters of GLO sections proved to be natural sample units for this kind of forest inventory. Unfortunately, an approximately one-square-mile land unit is by no means square on the map due to early primitive surveying techniques. In addition, the section is sometimes rather heavily subdivided.

The annotation problem for the commercial survey in which the first stage consisted of 1:40,000 scale aerial photography was solved by performing an individual resection for each photograph, followed by a prospective projection of all the relevant corner points of the land sections onto the photo-

graphs. In the ERTS-1 investigation we are adding two additional stages, namely a high altitude stage of U2 RC10 photography and a space platform stage from ERTS MSS imagery. Thus we were faced with the problem of also having to identify the land sections or multiples thereof as well as county lines and management unit boundaries on the U2 photographs and the ERTS images.

The ownership identification problem combined with our concern for good spatial correspondence between sample units on adjacent stages led us to our main objective for Task II, namely, to develop a precision annotation process for the U2 and ERTS images. The minor objective related to this main task was to investigate the accuracies with which points could be located on the U2 and ERTS imagery. In the case of ERTS, these accuracies would give us an idea of the smallest sample unit that can be used with this kind of imagery.

With regard to the third task, our objectives for the entire project are related to the three types of image interpretation methods presently available, namely: (1) manual interpretation, (2) interpretation using a television type image analyzing computer, and (3) digital interpretation of the computer compatible ERTS tapes provided by NASA.

As the sample units had been located on the 1:40,000 aerial images because of a previous contract, we could proceed with the image analyzing computer experiment at the start of this reporting period. The IMANCO Quantimet 720 was developed specifically for the analysis of blob-like features on a more or less uniform background with specific applications in the fields of histology and metallurgy. The analogy between these blobs and tree crowns on aerial photographs prompted the idea that led to one of the objectives for Task III, namely to investigate the applicability of this type of analyzer and to develop software to digest the outputs of this machine into meaningful forest inventory data.

4.0 WORK ACCOMPLISHED

4.1 Task II.

We had obtained good results with individual spatial resections of the 1:40,000 aerial photographs, which were performed with an efficient program with semi-automatic quality control. Thus, it seemed logical to apply the same principles to the U2 photography and the ERTS photography.

To control the resection, a set of known identifiable ground points is needed which can be measured on the photographs. These points can be taken from USGS topographic maps and put into digital form with a map digitizer. However, for the ERTS image we thought it necessary to obtain a much larger number of points, to make possible the evaluation of residual image distortions. As it is somewhat difficult to identify map features on ERTS imagery in rugged, mountainous terrain, we set out to identify a set of natural landmarks on the U2 RC-10 photographs that could also be readily identified on the ERTS images. We then used the U2 photographs to determine the ground

coordinates of these points by executing a block adjustment. This block adjustment then also provided the control for the resections of the U2 photographs. This approach was thought more desirable for the U2 stage because of its inherent greater accuracy due to simultaneous adjustments and the use of a precision MANN TA1/P monocomparator.

To minimize the programming effort, ground coordinates determined with the block adjustment, together with their measured plate coordinates, were fed into the existing resection program to perform the final transformation of the digitized section corners for the U2 stage.

Block Adjustment

The block adjustment was performed after the two strips of U2 photographs with ten photos each had been triangulated. Schuts triangulation and block adjustment programs were used for this purpose. Coordinates were expressed in a secant plane system, with its origin in the test area, to remove the influence of earth curvature. The standard errors computed with the control points and tie points used in the adjustment proved to be 12.8, 10.3 and 4.4 m, respectively, for Easting, Northing and height. The planimetric errors correspond to a point identification error of about 0.1 mm on the photographic plate. The results can be considered very good in view of the 1:126,000 scale of the RC-10 photography.

With the block adjustment completed and the coordinates of all ERTS identifiable points in hand, we then concentrated on the space resections of the ERTS MSS images.

Resection of ERTS MSS Images

In contrast to the resectioning of aerial photographs, the ERTS MSS images present two problems: (1) the MSS image is produced by a multi-spectral scanner with a geometry different than that of an aerial camera, and (2) there is little relief displacement in the image which is needed to determine all parameters of the resection.

The first problem is in part solved by the NASA data processing facility where the geometry of the MSS image is shaped to resemble the geometry of an aerial photograph, not considering relief displacement. As for the second problem, it can be shown that at least one parameter cannot be estimated when all the object points are near or in a plane. In addition, the narrow perspective bundle for the equivalent MSS frame photograph (Case, 1970) has, as a result, that additional ambiguities between parameters may exist. The problem can be circumvented by calculating some of the parameters from the orbital element with high accuracy. These values can then be inserted into the solution so that a fewer number of parameters need to be finally determined.

In the resection program for the annotation of the ERTS MSS images, we decided to take a completely general approach in which any parameter could be enforced at the value of its initial approximation by assigning appropriate weights. This approach can be implemented by using the parameter approximations in auxiliary equations in the linearized equation system:

$$\Delta p = p^{oo} - p^o + \epsilon \quad (1)$$

where:

Δp represents the correction to the approximation at the i th iteration

p^{oo} is the approximation of the parameter value

p^o denotes the parameter estimate to be enforced in the solution

ϵ is the difference between the least squares adjusted value of the parameter and the value to be enforced in the solution.

For the first iteration, p^{oo} is taken equal to p^o . Then, if we place a large weight on the auxiliary equation, ϵ will be close to zero, and Δp will also be close to zero, and the initial approximation, which is equal to the desired parameter value will not receive any corrections in the iterative process. Thus, the initially assigned parameter value will remain unchanged throughout the solution.

The normal equations take on the following form for n data points:

$$(\underline{X} \underline{W}^{-1} \underline{X}') \Delta = \underline{X} \underline{W}^{-1} \underline{Y} \quad (2)$$

with X' of the following form:

$$\begin{matrix} X' \\ (11,9,n) \end{matrix} = \begin{bmatrix} a_x^1 & a_x^2 & \dots & a_x^9 \\ a_y^1 & a_y^2 & \dots & a_y^9 \\ 1 & 0 & \dots & 0 \\ 0 & 1 & \dots & 0 \\ \vdots & & & \\ 0 & \dots & & 1 \end{bmatrix} \quad \begin{matrix} \text{(The third dimension} \\ \text{is not shown.)} \end{matrix}$$

where $a_x^1, a_x^2, \dots, a_y^1, a_y^2$ are the partial derivatives of the collinearity equations with respect to the nine resection parameters for a particular point.

The matrix has the following elements (only the first row is shown):

$$\begin{pmatrix} y' \\ (9 \times n) \end{pmatrix} = [\epsilon_x \ \epsilon_y \ (p_1^{\circ\circ} - p_1^{\circ}) \ (p_2^{\circ\circ} - p_2^{\circ}) \ \dots \ (p_9^{\circ\circ} - p_9^{\circ})] \quad (3)$$

where ϵ_x and ϵ_y are the discrepancies resulting from an evaluation of the collinearity equations for the point under consideration with the current set of parameter approximations.

The matrix W is a diagonal 11 x 11 weight matrix with unit weights in the first two positions, zero weights for those parameters that need to be estimated, and large weights (for instance, 100 unit weights) for those parameters that are to remain constant.

Thus, with the indicated solution we were free to fix or estimate parameters as needed. As the orbital path of the ERTS satellite is known quite accurately, the likely parameters to be enforced in the solution are the exposure station coordinates for the center of the image. For this purpose, the indicated latitude and longitude of the photocenters were taken from the ERTS catalog. To obtain the satellite altitude we prepared a program that computes the exposure station coordinates from orbital data furnished by NASA, given the GMT pertaining to the image center. However, we anticipated that the latitude and longitude indicated in the catalog would be more accurate than the estimates computed by our program, as we only included first-order harmonic terms. In the solution, either the artificial focal length or the altitude needs to be enforced. We selected the altitude since we assumed that scale change would be introduced in the bulk process through the introduction of an artificial focal length.

Coordinate Systems

The same secant plane coordinate system used for the block adjustment of the U2 photographs was used for the resection of the ERTS MSS images. The conversion from the geographic coordinate system to the secant plane coordinate system yields coordinates of the control points in a cartesian coordinate system. The XY plane of this system slices through the reference ellipsoid, so that the point elevations also reflect earth curvature.

The earth curvature accounts for part of the perspective displacement encountered in the bulk processed MSS image so that the use of the collinearity equation for the along-track direction in conjunction with the secant plane elevations was therefore partly justified.

Polynomial Fitting of the Residuals

To eliminate systematic trends remaining in the point residuals after the resection had been performed, we included in the resection program a general polynomial fitting routine, with which we could fit separate trend surfaces through the x and y residuals of the plate coordinates. This part of the program could then account for the unexplained remaining systematic distortions.

For the polynomial surface fitting we used hybrid orthogonal polynomials in the x and y plate coordinates, generated with a recurrence relation. The

maximum power of the polynomials is automatically determined by the program and then discounted to evaluate all possible power surface fits. For each power Root Mean Square Errors (RMSEs) were computed to assess the goodness of fit.

In the testing phase of the program we discovered that the polynomial fitting routine is general enough that, in terms of the residuals, almost identical results can be obtained by either performing a resection or by keeping all parameters fixed and then making the polynomial adjustment. Thus, with the present program one can either opt for the classical resection technique or obtain the optimum polynomial fit.

Experimental Results

Two ERTS MSS images, designated 103 and 104, were resected. These images covered our Redding (Northern California) test area. The ground control points were not distributed over the entire images. Rather, we confined them to those portions covering our forest inventory test site. In this regard, only 1/16 of image 103 was resected while the resection area for image 104 was approximately 1/6 of the total image area. A total of 18 points were used for image 103, while 30 points were used as input for the resection of image 104. In both cases we only attempted to estimate the three rotation parameters and the artificial focal length in the resection. The other parameters were held fixed as described before. The estimated values for the rotation parameters (yaw, roll and pitch) were : -11.173° , -0.156° , -0.025° , -10.984° , -0.161° and -0.019° , respectively, for images 103 and 104. To investigate the change in the rotation parameters and the exposure station coordinates in the case when the ground coordinates of the image center would be allowed to change we removed the weights from the image center coordinates and obtained the following results: the image center shifted by approximately 7.2 and 35.3 km in Easting and Northing, respectively, while roll and pitch increased to 2.056° and 0.423° , respectively. The combined RMSE for x and y remained practically unchanged. This experiment reinforced the notion that shifts of the image center can be compensated for by rotational changes, causing an ambiguity when trying to estimate both types of parameters.

The quality of the resections of images 103 and 104 is indicated in Table 1. First, we can see in Table 1 that the RMSEs vary from 0.119 to 0.233 mm. This variation amounts from one to two times the identification accuracy of the U2 RC-10 photography (0.1 mm), which is reasonable considering that the resolution of the MSS images is considerably less than that of the RC-10 photographs. Thus, we can conclude that the point identification accuracy is the limiting factor with respect to the resection quality.

Secondly, we can see in Table 1 that the polynomial adjustment does not appreciably improve the RMSEs. To test this hypothesis we can compare the RMSEs before and after polynomial adjustment by combining them in the form of an F statistic. For instance, an F value of 1.29 can be computed from the resultant RMSE of image 104 before polynomial adjustment (0.215) and from the resultant value after a third-degree adjustment (0.167). At the 90% confidence level this value should be greater than 1.51 to reject the hypothesis. This is not the case and thus we cannot confirm that the polynomial adjustment

Table I

RMSEs FOR RESECTION OF MSS IMAGES 103 AND 104
(millimeters)
(x 1000:meters on the ground)

Image	Resection Result	After polynomial adjustment		
		1	Power 2	3
<u>Image 103</u> (18 points)				
RMSE for x	0.142	0.129	0.123	--
RMSE for y	0.146	0.138	0.116	--
Resultant	0.144	0.133	0.119	--
<u>Image 104</u> (30 points)				
RMSE for x	0.233	0.225	0.217	0.187
RMSE for y	0.196	0.181	0.176	0.146
Resultant	0.215	0.204	0.198	0.167

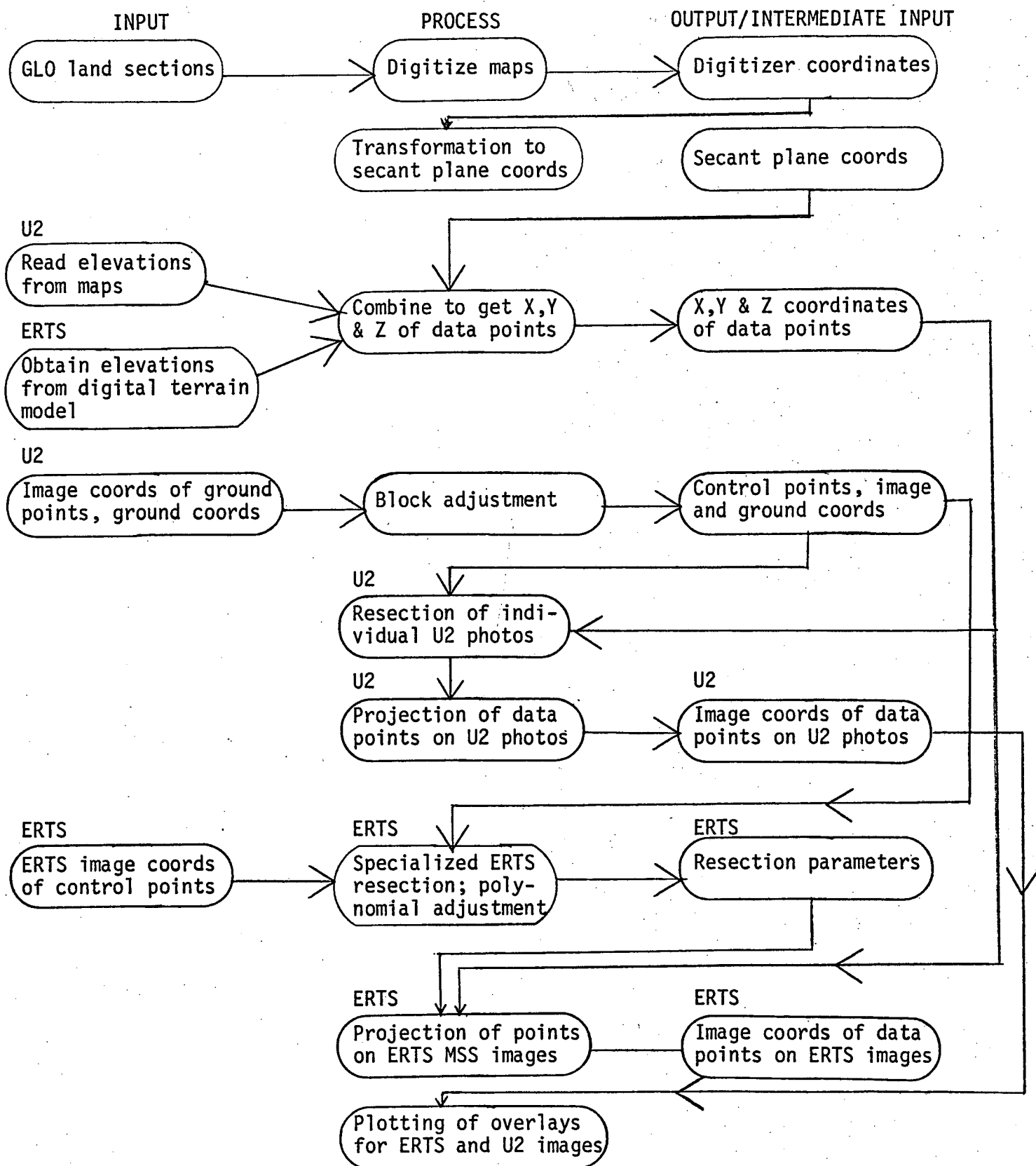


Figure 1. Flow diagram of ERTS MSS and U2 overlay manufacture.

contributes significantly to the overall accuracy.

An interesting result of some further experimentation was that the polynomial adjustment is useful when, for instance, all the parameters but yaw (azimuth) are held fixed. In this case we would have to compare an RMSE of 0.575 with one of 0.199 after a third-degree polynomial adjustment, giving rise to an F statistic of 6.49. In this particular case a first-power adjustment (fitting of a plane) still gave an RMSE of 0.232 indicating that a scale change in the form of an adjustable focal length was the most important adjustment mechanism that was not allowed to function when held constant.

With the resection results in the form of the covariance matrix of the estimated parameters, it should be possible to propagate the variances to determine the accuracy of individual projected points. However, we know that the accuracy of the individual point is bounded by the RMSEs for x and y obtained from the resection. Thus, it seems reasonable to assume a maximum standard error of 220 meters on the ground for any point projected on the MSS image within the resection area. Had we only made a scale change and used the image directly as a map, the error would have been in the neighborhood of 743 meters according to the data users handbook.

Production of Image Overlays for U2 RC-10 Photographs

The production of image overlays with annotated sample units both for the U2 photographs and for the ERTS MSS images took place as indicated in the flow diagram of Figure 1 in which the differences between procedures for ERTS and U2 images are indicated by boxes labelled ERTS or U2.

Three types of points needed to be annotated on the U2 and ERTS images, namely, the primary and secondary sample unit corner points, the county line points and the management unit boundary points. The units outlined on the U2 images were GLO land sections and fractions thereof. The secondary sample units were chosen as 2 x 4 combinations of individual sections. All points were digitized from 10 USGS maps at a scale of 1:62,500. Geographic coordinates were assigned to each digitized point by means of an interpolation method, using a set of map control points with known coordinates. The geographic coordinates were subsequently converted to secant plane coordinates. Elevations were read from the contour maps for all data points and were then added to the secant plane coordinates of the digitized points. Separate resections for the 20 U2 photographs were then calculated using the control results from block adjustment and the data point coordinates were transformed to image coordinates with the resection results. The image coordinates were finally plotted on stable material templates using a Hewlett-Packard 9100A calculator plotter. An example of a photo overlay is shown in Figure 3a.

Production of Image Overlays for ERTS MSS Images

After the resectioning of the space images was completed, the results were stored for subsequent use in the production of the image overlays. We decided to use the second-degree residual estimation for both images, even though the benefits of this estimation were not clear-cut, but we were convinced that the accuracy would not be degraded because of it.

A major difference between the method used for the U2 photographs and the ERTS images was that the elevations of the data points were produced by means of a digital terrain model in the case of ERTS. Obviously an enormous effort is required to read the elevations of USGS maps for 2000 data points, as was the case for the U2 overlays. An advantage of ERTS in this respect is that a relatively simple terrain model can be used to generate the elevations, as only the largest elevation discrepancies cause significant displacements on an ERTS image.

To produce elevations for the digitized points we developed a digital terrain model of which a hypsocline chart is shown in Figure 2. This model covers an area of 126 x 125 km of our Redding test area and includes part of the central valley, the Trinity Alps and the Mount Shasta area. In this area the maximum terrain variation is 14,000 ft. Elevations for the model were obtained by sampling an aeronautical chart with an 18 x 18 grid.

A test of the model showed that the RMSE of the actual terrain around the model surface amounted to 330 m. Under the assumption that the space image has a perspective geometry (including relief displacement), it can be shown that elevation errors in the order of 330 m would induce plate position errors of 37 micrometers whereas errors of 111 micrometers would be incurred by assuming a mean terrain elevation. However, the MSS image is formed by perspective projection (including terrain relief) in the cross-track direction only, while in the along-track direction after bulk processing the perspective projection would only be valid for general earth curvature. Thus, one would actually need two different terrain models to account for both types of perspective variation. At the present stage we used the one model shown in Figure 1 which accounts both for relief displacement and earth curvature since the elevations were transformed to the secant plane system.

At D in Figure 3a we have indicated a clear-cut GLO land section, which in terms of the primary 4 x 4 section sample unit occupies the second row, third position, counted from the upper left corner. The same cutover section is indicated by D in Figure 3b.

After the elevations were assigned to the digitized points they were processed through a program that sorts the points by image and projects them onto the image in a rectangular coordinate system defined by the registration marks at the four corners of the image. These coordinates were then plotted on stable transparent material with a Hewlett-Packard 9125A calculator-plotter at an enlargement ratio calculated by measuring a set of known distances on the enlargement.

The resultant overlay is shown in Figure 3b. In this figure the county line is indicated by A, the management unit boundary by B, and a primary sample unit corner by B. Note how the county line follows a set of mountain ridges extremely well.

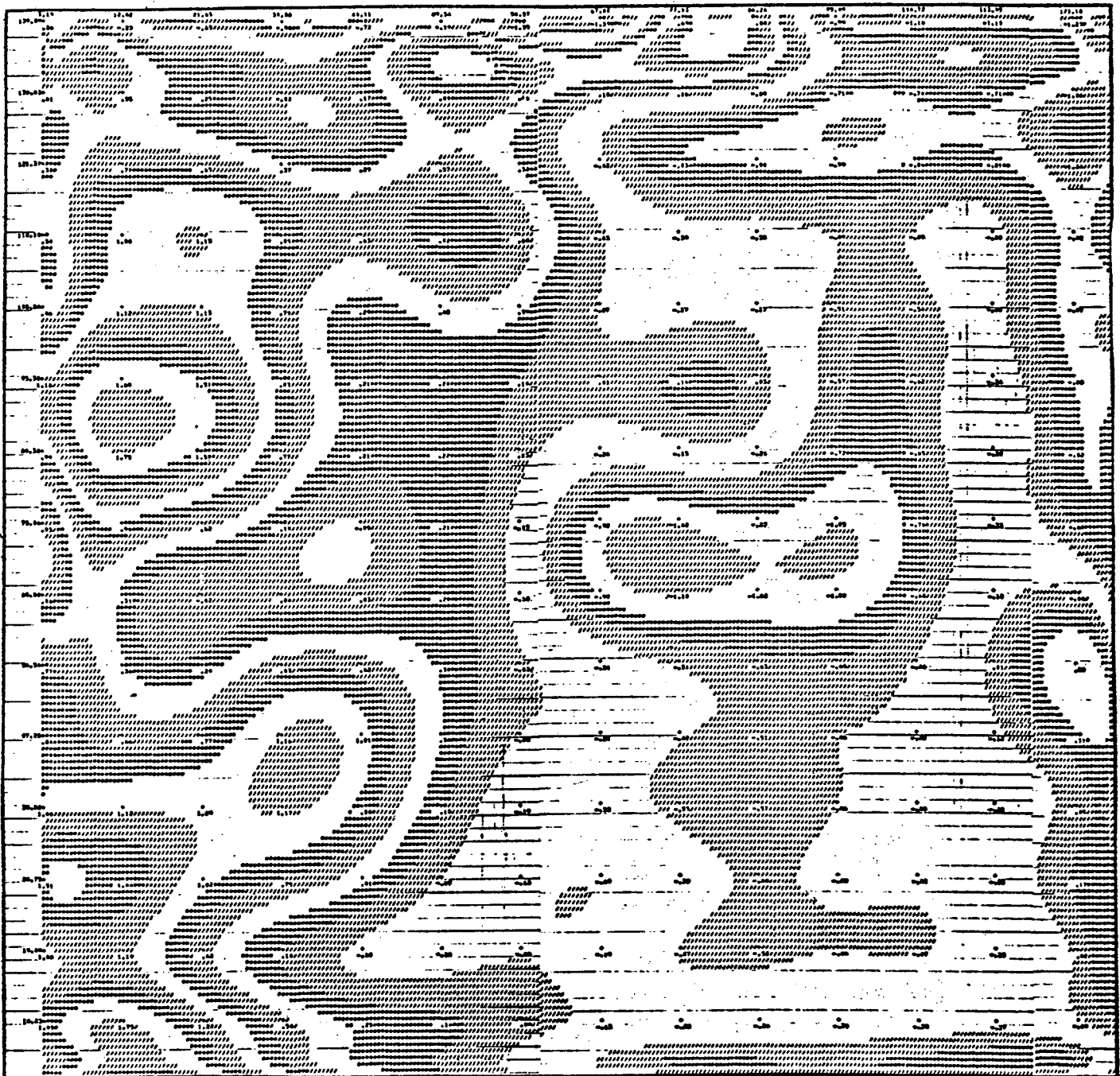


Figure 2. The digital terrain model illustrated by the hypsocline chart was used to assign elevations to digitized map points for subsequent correction of the boundary corners in the ERTS image overlay. The model covers an 125 x 125 km area and includes a correction for earth curvature.



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Figure 3a. U2 RC-10 photograph, scale 1:126,000 with second stage sample unit boundaries annotated by means of analytical resectioning. The light toned square indicated by "D" is a clear cut section which is also shown on the ERTS image of Figure 2b.

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Figure 3b. ERTS-1 MSS band 5 image, with primary sample unit boundaries annotated by means of analytical resectioning. County lines are indicated by "A", management boundaries by "B" and sample unit boundaries by "C". "D" indicates the one square mile clear cut area shown in Figure 2a.

4.2 Task III

Concurrently with the execution of Task II, a part of Task III concerning the use of the IMANCO image analyzer was carried out. For this investigation 1:40,000 B&W infrared aerial photographs enlarged to a scale of 1:24,000 were used. On these images were located a set of 167 sample strips with a width of 8 chains on the ground, all within Southern Pacific Land Co. parcels in Trinity County. Ground volume estimates were available for all 167 sample strips from a previous forest inventory.

Machine Configuration

Basically, the IMANCO Quantimet 720 is a density slicing machine also capable of performing measurements on the separated objects in the various grey levels. For the experiment the images were sliced such that the darkest level would mostly represent tree shadows and north slopes. The next to darkest level would consist of dark vegetation and the next to lightest level would be composed of light vegetation. The lightest level would mainly represent bare areas and bush.

In addition to density slicing the machine has a capability for measuring areas of the features in the various slices. For this purpose 8 area size categories were selected ranging from one picture point to an 8 x 8 cell of picture points, where a picture point was approximately 2 x 2 mm.

Two other features of the IMANCO Quantimet are the capabilities to make intercept counts and end counts. With the intercept count a horizontal chord intercepting the blob is counted whenever it satisfies the sizing criteria. In the end count, all the downward projections which fall within the frame to be analyzed are counted and can be grouped by size.

Modes of Operation

The IMANCO Quantimet is connected to a teletype with which selected variables can be recorded. For our experiment the following variables were selected for recording: (1) the total area in each slice, (2) intercept counts in each level by sizes, and (3) end counts in each level by sizes.

Analyses

Using the ground data from the Southern Pacific Land Co. survey, regression models were run where the dependent variable was gross conifer volume obtained from other regressions based on ground data and tree counts. The tree counts by size and species were obtained through the interpretation of large scale 70 mm photographs. The dependent variables were made up of data obtained from the IMANCO Quantimet.

The procedure used was to compute principal components of various combinations of variables both within and across density slices. Components were computed for the following configurations:

1. Across all variables within each slice.

2. Across intercept counts only within each slice.
3. Across end counts only within each slice.
4. Across end counts over all densities.
5. Across intercept counts over all densities.
6. Across area counts over all densities.
7. Over all variables combined.

After obtaining the principal components, correlation matrices were calculated to determine which principal components were most highly correlated to the dependent variable. After screening, various combinations of principal components were formed from the eigen vectors and used as independent variables in regression models. The results were somewhat disappointing. Correlation coefficients between the dependent variable and the individual components ran as high as 0.34, but most were less than 0.20 with several in the 0.20-0.30 range. When combinations were tried (multiple regressions) the highest multiple regression coefficient estimated was 0.55.

When outliers were successively removed from the data set, the correlations gradually rose to 0.76. However, so many outliers had to be removed to achieve this figure (see last Type I report) that we were simply trimming the tails of the distributions.

Our conclusion for the experiment was that the distribution of the dependent variable has too large a variance for the particular data set of IMANCO Quantimet variables to be useful.

5.0 WORK PROJECTED FOR NEXT REPORTING INTERVAL

At present, Task II of our ERTS-1 investigation has been completed. All image overlays are made and the image point coordinates of the various point types have been stored in a data file for use in a digital image retrieval system. In addition, a part of Task II concerning the use of the IMANCO image analyzing computer has been completed to the extent that under the present contract further research in this direction will not be attempted. Thus remains the last part of Task III, as well as final evaluations of the inventory under Task I.

The two remaining interpretation methods to be investigated under Task III are (1) manual interpretation of the U2 and ERTS images, and (2) digital interpretation of the computer compatible MSS tapes. Projected efforts for these projects are discussed in the following.

Manual Interpretation

To accomplish this task we will incorporate (1) existing forest inventory data available for the commercial forest property within our study area, and (2) the image overlays prepared during Task II, the U2 and ERTS-1 resectioning of property locations.

At the first level of interpretation the U2 resection overlays will be placed onto each of 21 respective U2 photographs covering the study area. The sections plotted on the U2 overlays will be clustered by delineating them into

the same 4 x 4 mile primary sample units as defined on the ERTS-1 image overlays.

A list of available volume data will be prepared for each cluster of sections included in the previous inventory and plotted on the overlay. Since approximately half of the area within each 4 x 4 mile cluster was not included in the previous inventory, separate volume predictions will be made for these sections and areas. These volume predictions shall be made on the basis of aerial stand volume tables based on crown closure and height as determined from photo interpretation. These predictions will be added to the existing volume data to arrive at a total volume prediction for each 4 x 4 mile sample unit.

At the next level of interpretation the ERTS-1 images shall be examined. The resection overlay placed onto the ERTS image shall reveal the location of each 4 x 4 mile sample unit within the test area. An independent prediction of timber volume present on each sample unit shall be made at this time. This estimate shall be based upon the percent of the area within a particular sample unit covered by forest as evaluated by the photo interpreter. A list of predicted volumes will then be prepared.

After this stage of interpretation the two lists of predicted volumes for the same primary sample units appearing on U2 and ERTS-1 imagery shall be statistically analyzed and reported.

Digital Image Interpretation

As outlined in the previously submitted data handling plan, we propose to complete the investigation in the following way: (1) introduce shading corrections on north slopes and perform simple density slicing within each primary sample unit, (2) develop a multispectral classifier and introduce texture data by means of Fourier and Hadamard transforms to the extent possible, as originally proposed.

To accomplish these objectives, we first will have to develop an image handling system with which primary sample units can be retrieved from the CCT's for digital processing. Work is now underway in this area and will be completed in the next reporting period. The coordinates to be used for retrieval were generated during Task II. The image handling system will be extremely flexible and make optimum use of disk and drum storage, to minimize tape handling. It will be possible to select subimages at three different levels.

In order to accommodate the texture information from the transform routines we will have to use a classifier. Research is now underway to develop a classifier based on a vector-field approach in n-dimensional space. This system may not be completed before the end of the contract; however, our effort will be continued under a Skylab contract.

6.0 CONCLUSIONS

As a part of our investigation, "The Development of a Multistage Forest Sampling Inventory System Using ERTS-1 Imagery", we developed a system to

provide precision annotation of predetermined primary sampling units on the ERTS-1 MSS images. In the development of this system we aimed for accurate results, but we realized there is a certain limit beyond which further refinement was not justified for a particular application--in our case, a forest inventory.

Therefore, we applied generalized resection theory using the collinearity equations, realizing that the geometry of the MSS image after bulk processing is not entirely commensurate with this theory. However, the results obtained with the investigation showed that at present the major factor limiting accuracy is not the basic model, but the accuracy with which known points can be identified on the MSS image. The maximum position error of 220 meters indicates that the delineation of the one square mile land section itself on ERTS-1 imagery would be technically feasible.

The conclusion for our work with the IMANCO Quantimet 720 image analyzing computer at scales smaller than 1:40,000 is that much experimentation and study would be needed to determine its full interpretation capability. As we are not prepared to perform an extended study under the present limiting funding, we will not attempt to make any further use of the machine at this moment.

Our work will proceed with the development of a digital interpretation capability, using the computer compatible tapes. A manual interpretation of the U2 and ERTS images will also be made. Interpretation results will be used to evaluate the efficiency of the use of the high altitude and the ERTS stages in the forest inventory.

7.0 REFERENCES

- Langley, P. G. New multi-stage sampling techniques using space and aircraft imagery for forest inventory. Proc. Sixth International Symposium on Remote Sensing of Environment. Univ. of Michigan. Ann Arbor, Mich. 1969.
- Forrest, R. B. Geometric processing of ERTS images. Bendix Research Laboratories. Southfield, Mich. 48076.